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Modelling the BMR of Species in Middle-Earth

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Abstract
The aim of this paper is to model the metabolic rates of the different species inhabiting the fictional world of Middle Earth, from the works of J. R. R. Tolkien. Hobbits, humans and elves were modelled by considering animal analogues for the basal metabolic rate (BMR). Constants of proportionality were determined to modify human BMR for different heights and weights. It was found that hobbits have the highest resting metabolic rate, while elves have the lowest. This is attributed to size and loss of heat due to changes in the surface area to volume ratio.

Introduction
In 1937 John R. R. Tolkien introduced us to the magical world of Middle Earth. From the peaceful greens of The Shire to the volcanic plains of Mordor, Middle Earth is filled with various forms of life. This includes dwarves, elves, hobbits, ents, wizards, humans and dragons. Species from Middle Earth, like those of the real world, carry out biological functions both at rest and while active. These functions require chemical energy derived from the food they consume. The turnover of this chemical energy is known as the metabolic rate.

Calories are units of the energy obtained from the consumption of food and lost in the process of normal metabolic functions. The increase in the rate of these functions during periods of activity gives rise to an increase in the required calorific intake. Oxygen (O_2) is required for the metabolism of food and carbon dioxide (CO_2) is produced as product of combustion.

Using the Harris-Benedict equation, which gives an estimate of human basal metabolic rate (BMR), the number of calories burned at rest (per day) can be determined. To calculate BMR for a human, gender, age, height and weight must be known. This paper aims to compare the BMR between three species in Middle Earth (hobbits, elves and men) by considering them as similar to animals on Earth.

Theory
If the humanoid species of Middle Earth are considered as variants of humans, a scale factor can be found for each species by modelling them as mammalian Earth species. The species used were chosen on the basis of their similar characteristics.

Woodland-dwelling herbivores were considered in modelling elves, ensuring that the animal chosen was larger than the animals used to model humans and hobbits. Therefore, *Capreolus capreolus* (Roe Deer) were used for elves due to their similar habitat, primarily vegetarian diet and fast reaction speeds. The human diet was considered to be Paleolithic as opposed to modern, the latter of which humans are not as well adapted for. This diet consisted of lean meat and berries, similar to that of *Vulpes vulpes* (Red Fox), the model animal used in this paper. *V. vulpes* is known to consume small animals, invertebrates and fruits, being omnivorous.

Finally, for hobbits, the herbivorous marsupial *Cercartetus concinnus* (Southwestern pygmy possum) was chosen due to its temperament, habitat within natural crevices (e.g. tree hollows), varied diet (e.g. nectar and insects) and nature as prey for larger animals such as *V. vulpes*. These animals were chosen so as to approximately mirror the size scale between men, elves and hobbits.

To consider the number of calories consumed by the aforementioned animals, the BMR was obtained, as shown in table 1, from [1].

Animal	BMR (L O_2 hr^{-1})	Average mass (kg)
Capreolus capreolus	8.3080	21.5
Cercartetus concinnus	0.0223	0.0186
Vulpes vulpes	2.4420	4.44

Table 1 – A table displaying the basal metabolic rates and average masses of the animals used to model the different species in Middle Earth [1].

From this data, a standard value for the BMR, considering a 1kg mass per animal, was calculated. Where every litre of oxygen consumed corresponds to the burning of 4.8kcal [2], this gives the calories burned by each animal due to its basal metabolic rate:

$$cal_{deer} = 44.51\ kcal\ kg^{-1}day^{-1}$$
$$cal_{possum} = 138.12\ kcal\ kg^{-1}day^{-1}$$
$$cal_{fox} = 63.36\ kcal\ kg^{-1}day^{-1}$$

From these values, using the fox (corresponding to humans) set to a ratio of 1, the scale factors for elves and hobbits were found:

$$Scale_{elves}: \times 0.7025$$
$$Scale_{hobbits}: \times 2.1799$$

To find the calories consumed for the BMR, the revised Harris-Benedict equation 1 for men [3] was then applied to height, weight and age estimates for the species. This was based on the concept of elves and hobbits as taller and shorter forms of humans, respectively.

When determining age, the lifespan of elves was scaled down to avoid skewed results and the Dúnedain were considered as average men.

$$BMR\ (kcal) = 88.362 + (13.397 \times weight\ in\ kg) + (4.799 \times height\ in\ cm) - (5.677 \times age\ in\ years) \quad (1)$$

The resulting number of calories consumed for each species at rest are shown in table 2 for 34-year old males:

Race (age 34)	Average Height	BMI	Average Mass (kg)	BMR (kcal / day)
Elf	~6'5'' – 9' [4] ~213.36 cm	18	81.94	1416.95
Human	176.5 cm [5]	23	71.65	1702.26
Hobbit	2' – 4' 3'6'' (average) ~106.68 cm	28	31.87	1818.61

Table 2 - A table displaying the heights, weights and calories consumed by male humans, elves and hobbits at rest. Masses were obtained by scaling the heights against human BMI ranges in relation to species body types.

Conclusion

The ratios obtained follow the expected trend for animal species, in that smaller animals are shown to burn more calories proportional to their body mass than larger animals. The correlation to species from Middle Earth is supported by the calculation of meal frequency. For example, for hobbits, comparing the ratio to humans would correspond to approximately 6.7 meals per day compared to 3 human meals, a sensible approximation based on the literature (6 meals) [6] and movie source material (7 meals).

The kilocalories consumed per day in an inactive state show that elves have the smallest resting energy requirements. This is supported by their longevity, as it is known that animals with slower cellular metabolic rates have longer lifespans. Similarly, the metabolism of hobbits is shown to be greater than for elves and humans. This is due to their small stature and hence, their smaller surface area to volume ratio which leads to a greater rate of heat loss.

References

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